

Commercial Orbital Transportation Services (COTS) Program Lessons Learned

HEOMD Knowledge Sharing Forum

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Agenda



- COTS Summary
 - SpaceX
 - Orbital
- Key Lessons Learned
 - From Program
 - From SpaceX
 - From Orbital



SpaceX COTS Summary

NASA

- COTS Space Act Agreement awarded August 2006 and amended in December 2010 with additional risk reduction milestones
- All 40 milestones completed in August 2012 for payments totaling \$396M

Demo Mission 1: December 8, 2010

Demo Mission 2/3: May 22-31, 2012

- Key Facts:
 - New Falcon 9 U.S. launch vehicle
 - New autonomous Dragon cargo spacecraft capable of carrying cargo to and from the ISS and LEO
 - New commercial launch facility at CCAFS, FL





ISS Capture of Dragon



Cape Canaveral Launch Site



Falcon 9

SpaceX COTS Demonstration Launches







SpaceX COTS Demo Mission C2+ Cargo Return



Dragon splashdown in Pacific May 31,2012



On recovery ship







TX Returned ISS cargo COMMERCIAL ORBITAL TRANSPORTATION SERVICES

SpaceX COTS Milestones



		\$M	\$M	\$M 2006			20	07			20	80			20	09			20	10		2011				2012			
	Milestones		Total	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
		<u>278.0</u>				İ				! !				 				 				! ! !							
1	Project Mgmt Plan	23.1	23.1		Sep 1	5								i 				i ! !											
2	Demo 1 SRR	5.0	28.1		V	lov 29				i ! !				i i i				i I I				i ! !							
3	Demo 1 PDR	18.1	46.2			F	eb 8			! ! !				 				 				! ! !							
4	Financing Round 1	10.0	56.2				Mar 1			ļ !				ļ				 				ļ							
5	Demo 2 SRR	31.1	87.4				Mar 1	5						ļ				! !											
6	Demo 1 CDR	8.1	95.5			<u>į</u>		A	ug 22					 															
7	Demo 3 SRR	22.3	117.8			į			Oct	i															į				
8	Demo 2 PDR	21.1	139.0			į			V	Dec 1	9																		
9	Draco Init. Hot fire	6.0	145.0			<u> </u>					Mar 21			 				i 											
10	Financing Round 2	10.0	155.0			<u> </u>					Mar 21			 				 				! ! !							
11	Demo 3 PDR	22.0	177.0			<u> </u>				Apı		Jun 2	7	ļ 				 											
12	Multi-Engine Test	22.0	199.0			<u> </u>				ļ !	Aug	4	Sep	ļ				 				ļ 							
13	Demo 2/3 CDR	25.0	224.0			<u> </u>				 		Dec	18	Jan				 											
14	Financing Round 3	10.0	234.0			į							Feb	В	Mar			i !		ļ					İ				
15	Demo 1 RR	5.0	239.0			į			Feb	V				>	 Mar			 	->	Jun 8									
16	CUCU Flight Unit	9.0	248.0			<u> </u>								M	ay\/	Ju	ul 23	i 											
17	Demo 1 Mission	5.0	253.0			<u> </u>				 		Sep		<u> </u>	- →	 un		<u> </u>	 	 		Dec 1							
18	Demo 2 RR	5.0	258.0							ļ !			Dec					 	 			<u> </u>		Sep		->	Mar 9		
19	Demo 2 Mission	5.0	263.0			<u> </u>								ļ	Jun			<u> </u>	 	 	 :		 	 N	-		-► V,	lun 7	
20	Cargo Int. Demo	5.0	268.0			<u> </u>								ļ 		Dec	: 18	Jan				ļ 				,			
21	Demo 3 RR	5.0	273.0			<u> </u>								i !	Jul	<i>-</i>		 	 						- > \	Dec		Au	ug 22
22	Demo 3 Mission	5.0	278.0			<u> </u>				<u> </u>				<u> </u>		Sep		 	 	 	 	 	<u> </u>		Jan	<u>/-</u>	->	Jun 7	









SpaceX Augmented COTS Milestones



	\$M	\$M	2007					20	80			20	09			20	10			20	11					
Milestones		Total	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	118.0						l I				! !				i i								 			
23 Modal Test Plan	5.0	5.0													<u>.</u>				Dec 16	5						
24 Modal Test	5.0	10.0																	Dec 16	5						
25 LIDAR Test (open loop)	5.0	15.0					 								 				Dec 16	3			 			
26 Solar Array Deploy Test	5.0	20.0					! !				i !				 				Dec 16				 			
LIDAR Test Plan 27 (closed loop)	5.0	25.0																		Mar 31						
Thermal Vacuum Test 28 Plan	5.0																		Mar							
29 Infrastructure Plan	10.0	40.0					 												Mar		/lay 10		 			
30 Thermal Vacuum Test	20.0	60.0																		Ju		Sep 14				
Test site Infrastructure 31 Implementation	5.0	65.0					! ! !				! ! !				T					V	Jun 23		 			
Dragon Trunk Acoustic 32 Test	10.0	75.0																			Jun 23		 			
LIDAR Test 6 DOF 33 (closed loop)	5.0	80.0																		А	ug 🗸	Oct	26			
Design Rev. Enhanced 34 Powered Cargo Accom.	5.0	85.0					 														A	ug 24				
Design Rev. Pressurized 35 Cargo Vol Increase	5.0	90.0					! !								†*************************************						V	ug 24	 			
Dragon EMI/EMC Test 36 (HITL)	10.0						! !				<u> </u>									Jul	VV					
Dragon Cargo Racks & 37 Hatch Simulator	3.0	103.0																				ug 26				
Ground Demo Enhanced 38 Powered Cargo	5.0	108.0																			Sep		26			
Launch site Infrastructure 39 Implementation	5.0	113.0					 				 				 				 		Sep	Oc	26			
Production Infrastructure 40 Implementation	5.0	118.0																			Sep	Oc	26			
SAA Total	396.0	396.0					 				! ! !] 			









Orbital COTS Summary

NASA

- Space Act Agreement awarded February 2008 and amended in December 2010 with additional risk reduction milestones
- All 29 milestones completed in November 2013 for payments totaling \$288M

- Maiden Test Flight: April 21, 2013

ISS Demo Mission: Sep. 18-23, 2013

• Key Facts:

- New Antares U.S. launch vehicle
- New autonomous Cygnus cargo spacecraft capable of carrying cargo to the ISS and disposing cargo from the ISS
- New commercial launch facility at Wallops Island, VA





Antares



Cygnus Approaching ISS



MARS/Wallops Launch Site



Orbital COTS Demonstration Launches

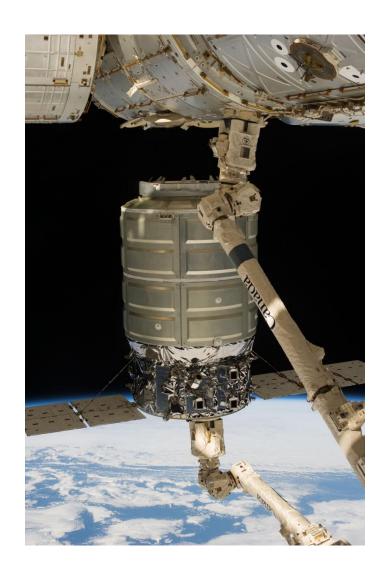






Orbital D-1 ISS Demonstration Mission









Orbital COTS Milestones



	\$M	\$M	M 2008					2009				2010				2011				2012				2013			
Milestones		Total	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
	170.0																						 				
1 Program Plan Review	10.0	10.0		Mar 3	1																		i ! !				
2 Demo Mission SRR	20.0	30.0		Jun	Jul	17	 	 			i ! !				i ! !								i ! !				
3 UCM PDR	10.0	40.0		Ju		\ug 14					i ! ! !				i ! ! !				i ! ! !				i I I L				
4 DELETED															 								 				
5 COTS Int/Ops Facility	10.0	50.0		Se	p 22	Oct					 												! ! ! !				
6 PCM PDR	10.0	60.0				V∵ No	1				 				! ! !								 				
7 DELETED															i ! !								i I I				
8 IP&CL Submission	10.0	70.0					V	eb 18			i ! !				i ! ! !								i I I				
9 ISS Phase 1 SRP	10.0	80.0						Mar 2	27		 				 				 				 				
10 COTS System PDR	20.0	100.0			Sep		-	M	ay 22		 				 				 				 				
11 PCM CDR	10.0	110.0							Ju	l 31																	
12 Cygnus Avionics Test	10.0	120.0						Jun	>	ug 13													i ! !				
13 ISS Phase 2 SRP	10.0	130.0							ug	-	Nov 6				i ! ! !				 				i ! !				
14 COTS System CDR	10.0	140.0					Mar		► Sep	/	- 🖊	Mar 2	3		 				 				 				
SM Core Assembly 15 Complete	7.5	147.5						 	Oct	₩	Dec		A	ug 30	! !												
16 SM Test Readiness Review	7.5	155.0								Jan	.,- →	VApr		N	bv 17												
17 SM Initial CPT	5.0	160.0									i L	lay			<u> </u> 	Jun		->	Dec 14	1			i ! ! !				
18 LV Stage I Assy. Complete	2.5	162.5					 				 		Sep		<u> </u>		- ▶ Sep	<u> </u>							Jul	11	
19 Cargo Int. Demo	2.5	165.0													Dec 6												
20 Mission Readiness Review	2.5	167.5											Oct	√ -	<u></u>			oct V	<u> </u>						Jul	27	
21 System Demo Flight	2.5	170.0												Dec				Dec							– – – Nov	6	









Orbital Augmented COTS Milestones



	\$M	\$M	2008					2009				2010				2011				20	12					
Milestones		Total	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	<u>118.0</u>																									
22 Test Flight Mission Review	20.0	20.0					 				 			V	Dec 1	5			 				 			
23 Test Flight Mission Analys.	10.0	30.0					! ! !				 				VF	eb 23			ļ !				! ! ! !			
Cygnus Mass Sim. (CMS) 24 Design Review	10.0	40.0					! ! !				 					Mar ()3						 			
Install Add'l PITL 25 Simulators	5.0	45.0													Apr	V	lay 6									
26 PROX FEU Test Unit	5.0	50.0													<u> </u>	/lay	Jun 1	7								
27 Maiden Flt Stg 1 Core Del.	24.0	74.0					 				 				 	Apr	28		 				 			
28 Maiden Flt Uppr Stage Del.	20.0	94.0									 						Jun 21									
29 Maiden Flt CMS Delivered	10.0	104.0									i ! !						Jun 20						i ! !			
30 Maiden Flt Stage 1 Assy.	10.0	114.0					i ! ! !] 		V _{Jul}				+	ер 17	 			
31 Maiden Test Flight	4.0	118.0					ļ 				 				<u> </u>		Oct	V -					<u> </u>	M	ay 9	
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SAA Total	288.0	<u>280.5</u>													i											

COMMERCIAL ORBITAL TRANSPORTATION SERVICES





Key Lessons Learned from Program



- Government seed money was highly leveraged
 - Commercial partners funded over 50% of COTS development costs
- Fixed price milestone payments maximized incentive to control cost and minimize schedule delays
- Minimum firm requirements along with commensurate Government oversight were key to fostering innovation and reducing life cycle development costs
 - Goals (vs. requirements) were established to open trade space and optimize design
 - Firm requirements were identified only where necessary to assure the safety of the ISS and crew
 - ISS interface requirements evolved over time and were coordinated in a collaborative manner with the commercial partners
- A portfolio of multiple partners with different capabilities assured a balanced approach to technical and business risks
 - Increased the chances of at least one successful partner
 - Market forces kept development and operational costs in check
- Commercial friendly intellectual property/data rights and limited termination liability encouraged investment of private capital



Lessons Learned from Program (Cont.)



- NASA commitment to purchase operational services greatly improves the ability for companies to raise funds
- NASA does not have the statutory authority to provide Government Furnished Equipment (GFE) under a SAA
 - Even though originally contemplated in the SAA and in the best interest of the Government, COTS
 had to revert to loan agreements and cumbersome GSA excess procedures to transfer equipment
 to facilitate berthing with the ISS
- Augmentation of funding late in the program enabled additional risk reduction testing not initially affordable
 - Directly contributed to the successful first attempt berthing of SpaceX Dragon to ISS
 - Would be difficult to predict how much, if any, to hold in reserve during program formulation and initialization to protect for such milestone adjustments
- COTS model for public-private partnerships worked!

Key Lessons Learned from SpaceX



- Design, Test and Repeat (engineering units prior to qualification)
 - This philosophy can be better than just detailed analysis and only one test –learn much more
 - Need to have a team that can react and make changes quickly
- Use of COTS electronics parts is feasible (instead of all S-level parts) thru use of some radiation screening/tests and better architecture decisions (redundancy and reboot capability)
 - Saves significant cost and schedule over traditional avionics
 - Previous Cost "GE Price" modeling experience was "No matter how many runs done with varying complexity, similarity vs new design, etc- the cost and schedule of the <u>Avionics and software</u> drove the project cost." Much more expensive than even massive structure or thermal systems.
 - Note: if total length of a project can be reduced 6-12 months by using readily available parts and processes, you really save the monthly burn rate of the whole project for that many months.
 - Just gets projects done faster, so NASA could be more responsive and can do more things
- Design with cost in mind
 - SpaceX paid much more attention to the cost of parts and component in the initial design phases than NASA contractors traditionally do; to the point of building many things in house, because it was perceived to be too expensive to buy vendor part. They always questioned why it can't be done less expensively and pushed back on costly requirements.
 - In-house production has the added benefit of allowing better schedule control than from sub-tier suppliers and allows a streamlined change/update process.



Key Lessons Learned from SpaceX (Cont.)



- NASA observed SpaceX's use of "WIKI tools" for multiple critical business and engineering processes saves time—trying to move to a paperless environment.
 - Microsoft SharePoint and Confluence primarily for team processes and general info that they want teams to have instead of some team meetings
 - Provided models instead of large documents in some cases (FEM models and summary vs structural analysis report)
 - TRAC tickets are being used for issues, changes and risks by many teams.
 - Provides a "virtual" meeting to ask questions and throw out ideas. Tracks all the comments for others to look at. Eventually, bringing them to closure and having all the managers and responsible engineers sign off on it.
 - Saves time (schedule) by letting people look at ticket when they can fit it in their schedule and not have to wait for a meeting to be called when everyone can attend. → a Virtual board/review if you will.
 - NASA use suggested for simple issues, changes and risk (identify them as such), but move quickly to a meeting if not coming to timely closure or unclear questions arise.



Key Lessons Learned from Orbital



- Design Review Process Independent Review Teams
 - Use of independent review team (IRT) of "experienced" experts to serve as design review team can be very effective
 - IRT typically not bound by cost or schedule and can serve as a common sense sounding board for design and programmatic decisions
 - Membership of team should remain consistent throughout program (to the extent practical)
 - Review team findings should go to level of management above program manager for disposition/review
- Use of "standard building block" designs
 - NASA standard practices typically utilize custom or first use designs, whereas commercial leverages existing "product line" designs
 - Lowers technical risk due to vast experience with designs/components
 - Could also potentially lower cost & schedule due to potentially eliminating the need for additional qualification testing (where applicable)
 - Does not come without risk however...
- Leveraging common goals with all constituents (i.e. States, local governments, DOD,...)
 - NASA frequently "goes it alone" on programs and supplies all funding
 - Commercial industry realizes the benefits of competition and synergistic desires
 - Example State of Virginia had interests in developing spaceport (i.e. MARS) and supplied significant funding
 - Example Industry partners, in some cases, provided funding for unique hardware in exchange for IP rights

Key Lessons Learned from Orbital



- NASA can embrace cultural shift of working with "Commercial" partners, but it is a continuing challenge
 - NASA has immense technical capability
 - NASA needs to understand partner challenges, both technical and programmatic
 - NASA needs to avoid "grading" systems designs and offer solutions that consider partner challenges
 - If we show value, industry will "open up"
- Communication & trust is essential
 - Partners, not customers or "suppliers"
 - Regular tag-ups
 - Talk often and early...
 - Relationship should be built to last and therefore needs to be protected and nurtured
- Breaking interfaces/systems which were not designed for multi-party use is difficult and needs careful thought & consideration



